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Federal Communications Commission
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Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
The Development of Operational,	)	WT Docket No. 96-86
Technical, and Spectrum	)	
Requirements for Meeting	)	
Federal, State and Local Public	)	
Safety Agency Communication	)	
Requirements Through the	)	
Year 2010	)	DOCKET FILE COPY ORIGINAL

To: The Commission

COMMENTS OF NIPPON TELEGRAPH AND TELEPHONE CORPORATION

Nippon Telegraph and Telephone Corporation ("NTT"), by its attorneys, hereby submits its comments in response to the Notice of Proposed Rule Making ("NPRM")[1] issued in the above-captioned proceeding on April 10, 1996. NTT commends the Commission for its continuing effort to address comprehensively the expanding needs of public safety wireless communications.

I. INTRODUCTION.

The Commission's stated goal in this proceeding is to foster "a regulatory environment where agencies involved in the protection of life and property have the communications resources they need to carry out their mission and an opportunity to select from a wide range of advanced wireless communications services."[2] NTT submits that, if the

[1] FCC 96-155 (April 10, 1996).

[2] NPRM at ¶18.

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Commission is to achieve its goal, it must focus on practical, reasonably available solutions to the problems confronting the public safety community.

The record assembled by the Public Safety Wireless Advisory Committee ("PSWAC") conclusively demonstrates that through the deployment of new technologies -- technologies that have long since left the "drawing board" and are capable of commercialization in the very near term -- combined with rational allocation and assignment policies, many of the anticipated needs of the public safety community can be met without substantial added expense.

Below, NTT will describe in detail its state-of-the-art, spectrum-efficient (5 kHz) RZ SSB (acronym for "Real Zero Single Side-Band") technology and will demonstrate how emerging technologies such as RZ SSB can enhance public safety officials' abilities to perform their missions. The critical decision facing the Commission is how to establish a scheme of regulatory requirements and incentives that will motivate manufacturers to bring these technologies to market in a timely manner.

II. NTT'S INTEREST IN THIS PROCEEDING.

NTT was an active participant in the Commission's "Refarming" proceeding,[3/] which was intended, inter alia, to create a more efficient channelization scheme for many of the private land mobile radio bands, including certain of those allocated for public safety use. In

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[3/] Notice of Proposed Rule Making, In the Matter of Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them, 7 F.C.C.R. 8105 (1992); Further Notice of Proposed Rule Making, In the Matter of Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them and Examination of Exclusivity and Frequency Assignment Policies of the Private Land Mobile Radio Services, 10 F.C.C.R. 10076 (1995).

its various comments in that proceeding,[4] NTT detailed the results of its RZ SSB development program. Further, NTT has conducted demonstrations of a prototype RZ SSB system.[5] In brief, NTT demonstrated that RZ SSB-based equipment can provide an optimal solution to many of the concerns under consideration in this proceeding, and it can do so in the near term. As is demonstrated in the Technical Appendix, there remain no significant technical obstacles to the successful near-term commercialization of RZ SSB technology.

III. SPECTRUM CONGESTION AND EXPANDING PUBLIC SAFETY COMMUNICATIONS NEEDS.

Public safety agencies' demand for mobile communications has increased rapidly in recent years.[6] Public safety agencies have indicated that, in addition to high quality voice transmission, their future systems must provide facsimile and snapshot capabilities -- allowing for the wireless transmission of text, black and white imagery, gray-scale or color imagery -- and perhaps color full-motion video as well.[7] According to PSWAC, "[t]he currently allocated

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4/ Comments of NTT, filed May 28, 1993; Reply Comments of NTT, filed July 30, 1993, Comments to the Further Notice of Proposed Rule Making of NTT, filed November 20, 1995.

5/ In February of 1995, several members of the FCC staff attended a mobile demonstration of a prototype RZ SSB system conducted in the Washington D.C. area. The following month, NTT conducted a similar demonstration in Denver, Colorado. Since those demonstrations, NTT has created a smaller prototype and currently is developing a handheld model.

6/ Report and Plan for Meeting State and Local Government Public Safety Agency Spectrum Needs Through the Year 2010, 10 F.C.C.R. 5207, 5219 (1995) ("2010 Report"). See also Remarks of Michele C. Farquhar, Chief, Wireless Telecommunications Bureau, before the APCO Conference, August, 12, 1996.

7/ NPRM at ¶ 48 (citing Coalition of Private Users of Emerging Multimedia Technologies (COPE), Petition for Rule Making, Spectrum Allocations for
(continued...)

Public Safety spectrum is insufficient to meet current voice and data needs, will not permit deployment of needed advanced data and video systems, does not provide adequate interoperability channels, and will not meet future needs under projected population growth and demographic changes."[8] PSWAC concludes that use of advanced spectrum-efficient technologies, in addition to allocation of additional spectrum, is necessary to meet public safety agencies' communications needs.[9]

NTT believes that, in facilitating the transition to use of spectrum-efficient technologies, the Commission should adopt the following approach. First, the Commission should establish spectrum efficiency standards to ensure that, within a time frame that permits current spectrum users to amortize their existing equipment, all users ultimately will employ spectrum-efficient equipment. Second, the Commission should provide incentives to encourage as expeditious a transition to the most spectrum-efficient technology available as is practicable, given the budgetary constraints that confront public safety licensees. Finally, the efficiency standards adopted by the Commission must be technology-neutral, so as to ensure that a competitive marketplace will continue to advance the state of the art.

7/ (...continued)
Advanced Private Land Mobile Communications Services, filed December 23, 1993). See also Final Report of the Public Safety Wireless Advisory Committee, ¶¶ 2.1.13, 2.1.15, 2.1.16 (1996) ("PSWAC Report").

8/ PSWAC Report at ¶ 2.1.10.

9/ PSWAC Report at ¶ 3.1.

A. <u>The Adoption Of A Spectrum Efficiency Standard Is Necessary To Meet The Public Safety Community's Near-Term And Long-Term Needs.</u>

Just a decade ago, mobile two-way equipment using analog Frequency Modulation (FM) in 25 kHz channels was considered state-of-the-art.[10] Today, there are numerous technologies that provide the same (or even more) features than the 25 kHz FM technology, using far less bandwidth.

For example, RZ SSB operates within a 5 kHz-wide channel, accommodating a variety of information signals in an available occupied bandwidth from 300 Hz to 3.4 kHz; the RZ SSB emission mask is such that, for most applications, adjacent-channel operations can be co-located. Unlike conventional SSB receivers, RZ SSB uses Phase-Modulation reception to achieve immunity from fading. The RZ SSB system supports speech, high-speed voice-band MODEM, G3 facsimile, still JPEG pictures (Motion JPEG - Joint Photographic Experts Groups), and slow-scan video. RZ SSB can achieve signal quality that is at least as good as, and often better than, narrowband (12.5 kHz) FM. Because the information bandwidth (3.1 kHz) is identical to that of an ordinary telephone line, the system provides a transparent interface with the public switched telephone network. The cost of a RZ SSB-based system will not differ significantly from that of a current-band FM system, because the vast majority of the necessary components essentially are standard "off-the-shelf" products currently in use in conventional radios.

Given these substantial advances in technology, NTT submits that the Commission can and should establish a baseline efficiency standard (whether based on "throughput" or bandwidth), which essentially all new equipment will have to meet as part of

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10/ <u>NPRM</u> at ¶ 21.

the equipment authorization process. Moreover, contrary to the approach taken in the Refarming proceeding, the regulatory scheme, if it is to prove efficacious, cannot permit the continued sale of non-narrowband equipment beyond some reasonable transition period.[11/] Otherwise, few, if any, manufacturers will undertake the expense of bringing a new generation of product to market in the near term; if the Refarming proceeding proved nothing else, it demonstrated that institutional inertia and an essentially uncompetitive marketplace will conspire against significant technological advances, even in the face of a clearly perceived crisis looming in the not-too-distant future.

NTT supports the Commission's suggestion of requiring the use of very narrowband technologies immediately on all newly allocated spectrum.[12/] This step alone, however, will not have much impact on the present congestion in the existing bands. If the Commission is to have any significant hope of reducing that congestion in the near term, it must adopt a universal very narrowband channelization plan for all public safety allocations, while still allowing a transition period that permits current licensees to amortize their existing equipment. The Commission took some initial steps in this general direction in the Refarming proceeding. However, as is evident from the aftermath of that rulemaking, a more aggressive

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11/ Recognizing that the Commission's current policy of type acceptance "may not be sufficient" to achieve the goals outlined in this proceeding, the Technology Subcommittee of the Public Safety Wireless Advisory Committee recommended considering "[t]he imposition of a date certain for all equipment conformance." PSWAC Report at ¶ 4.5.2.

12/ Report 2010 at 5244.

approach is required if the Commission hopes to achieve a significant near-term reduction in the existing congestion levels.

B. Incentives Are Necessary To Facilitate The Transition To Narrowband Systems.

To ease current spectrum congestion, and to provide for the projected spectrum needs of public safety agencies, NTT encourages the Commission to create a regulatory environment that fosters the use of the most spectrum-efficient technology available. For example, the Commission has suggested offering exclusivity to users who move to very narrowband (e.g., 5 kHz) technologies. Providing users with exclusive use rights would encourage more efficient use of spectrum. Additionally, providing users who move to very narrowband technologies the right to lease excess capacity might make a more rapid transition to the use of spectrum-efficient technology economically feasible.[13/]

Finally, the Commission should consider permitting licensees who convert from, e.g., 25 kHz channel equipment to 5 kHz equipment, to retain at least some significant percentage of the "new" channels created by the conversion. Thus, a current 25 kHz licensee who converts to 5 kHz technology should be permitted to operate perhaps three or four of the five new channels created from its original 25 kHz channel. NTT believes that adoption of any or all of the above-discussed incentives would expedite the transition to narrowband systems.

13/ Although the cost of a RZ SSB-based system would not be significantly different from that of a current-band FM system, providing users with this incentive might allow them to adopt a new spectrum-efficient system, prior to full amortization of their old equipment.

C. Technology-Neutral Efficiency Standards Are The Best Means Of Addressing The Public Safety Community's Needs.

While NTT obviously believes that RZ SSB-based equipment can solve many of the problems identified in the NPRM and in the PSWAC proceedings, NTT agrees with the Commission that a competitive marketplace will best provide users with the widest variety of available service features at the lowest costs. If other technologies can be developed that will offer more versatility with greater spectrum efficiency, so be it. The Commission's goal should be to continue to advance the state of the art, and this is most effectively achieved through technology-neutral rules. According to PSWAC, "committing broader discretion to users is essential to affording incentives for advanced technologies."[14]

Competition will provide existing manufacturers and new entrants with incentives for creating better equipment with more features. If the Commission were to mandate use of a particular technology, manufacturers would have little incentive to undertake the expense of developing better technologies and seeking regulatory changes to permit their deployment; the end result would not be altogether different from the status quo, as illustrated by the outcome of the Refarming proceeding. On the other hand, if users were able to choose from a number of different products, manufacturers would be forced to enhance their products to meet users needs. Therefore, NTT urges the Commission to foster a competitive marketplace by adopting technology-neutral efficiency standards.[15]

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[14] PSWAC Report at ¶ 2.2.8.

[15] PSWAC recognized the importance of allowing for flexible mandates, stating "[f]lexible mandates are needed in order to encourage the rapid deployment of (continued...)

IV. THE NEED FOR INTEROPERABILITY.

Adopting technology-neutral standards does not preclude the Commission from allowing for, or mandating some form of, interoperability. While maintaining technology-neutral standards, public safety equipment could be made interoperable through the use of multimode radios. However, in light of the Commission's experience in the Refarming proceeding and the record established by PSWAC, NTT would argue against a "full" interoperability requirement, which could add significant expense and complication without countervailing benefit.

Rather, the most effective course for the Commission to pursue regarding interoperability would be to require that new equipment be made partially interoperable, facilitating communication through a common technology during emergency situations, while still allowing users to select their own specialized technologies for daily use. PSWAC's suggestion of universal "mutual aid" channels, using a common baseline technology, would achieve this goal without significant expense and without hampering technological progress.[16/] If the Commission selected a technology that is used commonly today, such as analog FM, effective interoperability could be achieved at very low cost, while the competitive marketplace would be maintained, because the primary technology would not be mandated and users would be able to select from a wide variety of technologies with different service features. NTT supports the use of open and fair processes in the development and adoption of future standards for public safety wireless communications equipment and systems.

15/ (...continued)
new technologies." PSWAC Report at ¶ 2.1.19.

16/ See PSWAC Report at ¶ 2.2.11.1.

CONCLUSION.

The NPRM and the PSWAC Report make clear that a host of very narrowband technologies can be available in the near term, assuming a rational regulatory climate. Moreover, at least with respect to RZ SSB-based systems, there should be no significant difference in the cost of 12.5 or 25 kHz technologies on the one hand and 5 or 6.25 kHz technologies on the other. By establishing and implementing an aggressive spectrum-efficiency standard now, coupled with significant licensee incentives, the Commission can ensure that there will be sufficient customer demand to inspire manufacturers to make the investments necessary to commercialize these efficient technologies in the near term.

Based on the foregoing, NTT urges the Commission to adopt a new regulatory structure for public safety wireless communications that incorporates the points discussed above.

Respectfully submitted,
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TECHNICAL APPENDIX

This technical appendix provides an overview of the RZ SSB (acronym for "Real Zero Single Side-Band") technology developed by Nippon Telegraph and Telephone Corporation ("NTT"). It also summarizes the experimental results of field tests of the RZ SSB system that NTT conducted in the metropolitan area of Tokyo, Japan, and describes demonstrations conducted in Washington, D.C. and Denver, Colorado.

I. NTT'S DEVELOPMENT OF RZ SSB.

RZ SSB is a product of NTT's continuing efforts to develop spectrum-efficient mobile technologies. Work on the RZ SSB project began in 1984, shortly after narrowband (12.5 kHz) FM cellular telephone services were introduced commercially in the Japanese marketplace. The information bandwidth of the FM signal was restricted by regulation to a maximum of 3 kHz, which is 400 Hz narrower than that used for telephone signals, and insufficient to carry many useful signals such as G3 facsimile at 9.6 kbps.

The goal of NTT's RZ SSB research was to develop a narrowband system capable of seamlessly interfacing with the telephone network and transmitting a wide variety of signals. Therefore, NTT researchers started with the premise that the frequency bandwidth of the information signal must range from 300 Hz to 3.4 kHz.

Given these bandwidth constraints, a Single Side-Band ("SSB") modulation method was chosen to achieve 5 kHz channel spacing. However, conventional SSB transceivers must be equipped with Automatic Gain Control

("AGC") and Automatic Frequency Control ("AFC") circuits in order to combat fading, and these circuits do not work well in severe fading environments. To date, researchers have achieved only modest results in attempts to improve the performance of AGC and AFC circuits.

NTT decided to take a completely different approach, aimed at eliminating these performance-limiting circuits. Accordingly, through extensive experimentation, a modulation technique, not dependent upon recovery of information from the envelope of the SSB signal, was developed. This modulation technique allowed for recovery of information despite signal fading. After achieving experimental success on the technique that would become RZ SSB, the researchers encountered a technical paper entitled "Information in the Zero Crossings of Bandpass Signals," which was published in the Bell System Technical Journal by Mr. B. F. Logan, Jr. of Bell Labs in 1977. By using "entire function theory," Mr. Logan demonstrated that zero crossings of a band-pass signal could carry information signals without any loss. Mr. Logan's paper provided theoretical support for NTT's approach. The band-pass signal described in Mr. Logan's 1977 paper is identical to the RZ SSB signal.

However, Mr. Logan's article concluded that recovery of an information signal from the zero crossings appeared to be "very difficult and impractical."[1/] After expending considerable time and effort, NTT's research team discovered an easy and practical solution for recovering an information signal from

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1/ B.F. Logan, Jr., "Information in the Zero Crossings of Bandpass Signals," Bell System Technical Journal, Apr. 1977, at 487.

the zero crossings of an SSB signal. The procedure was successfully embodied in an inexpensive Large Scale Integrated ("LSI") circuit using a digital signal processing ("DSP") technique. This LSI "linearizer" circuit is the heart of RZ SSB.

II. OVERVIEW OF RZ SSB TECHNOLOGY.

RZ SSB employs a combination of two established technologies: SSB signal transmission, and phase modulation reception.[2/] The former maintains the narrowband characteristics of the modulated signal and the latter provides immunity against fading and interference, as verified through extensive laboratory experiments and field tests. Because RZ SSB is a waveform-preserving system, it can transparently carry digital signals, as well as analog signals, even in a fading environment. Transmission performance is superior to that of conventional SSB systems.

RZ SSB employs two-branch space diversity reception to enhance the quality of signals demodulated in severe fading environments (e.g., when at least one of two parties communicating with each other is traveling at high speed).[3/] Diversity reception is not required in non-mobile environments or for relatively slow speeds, such as walking and slow vehicular speeds. The improvement in signal quality is

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2/ The zero-crossing information can be found in the phase component of the signal.

3/ The diversity reception technique uses equal gain combining. In this method, the gains of each of the two branches are made equal, and the signals are coherently summed at a combining circuit. The coherent combination is accomplished using a random FM noise canceler whose output signal phase is completely independent of the input signal phase.

fully achieved with antenna spacings as small as one-tenth of the wavelength.[4/] Diversity reception also greatly improves immunity to interference.

A linear modulation technology with a narrow channel spacing inherently suffers from amplitude linearity and frequency stability problems. RZ SSB reduces the problem of power amplifier amplitude linearity by employing a Cartesian feedback technique. It also diminishes the problem of frequency stability by using a digital TCXO or OCXO.

True 5 kHz bandwidth is achieved by using a bandpass filter developed by NTT with very sharp attenuation characteristics. Despite its steep slope, this filter does not cause excess degradation, owing to the fact that RZ SSB is inherently among the amplitude-modulation families.

The employment of analog LSI circuits in the RZ SSB transceiver reduces transceiver size and power consumption. While use of LSI circuits with analog systems generally has been difficult, this has not been the case for RZ SSB; these problems have been overcome with the use of, among other things, MOS[5/] analog signal processing techniques.

III. FIELD TEST RESULTS.

Shortly after NTT developed RZ SSB in the laboratory, a working group within the Ministry of Posts and Telecommunications ("MPT") asked NTT to

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4/ Y. Ebine and Y. Yamada, "Vehicular-mounted diversity antennas for land mobile radios," IEEE VTC' 88, Pennsylvania (June 1988). At 220 MHz, for example, one-tenth of the wavelength is approximately 14 cm.

5/ MOS is that acronym for Metal Oxide Semiconductor.

conduct field tests of the RZ SSB technology operating within a 5 kHz channel spacing. In February 1991, NTT began an extensive series of tests using channels in the 150 MHz band in the Shinjuku metropolitan area of Tokyo, a mobile radio environment presenting typical spectrum congestion problems and spectrum efficiency challenges. A base station was established at NTT's Nakano building, and a three-element Yagi antenna was raised at its antenna site at a height of approximately 300 feet. A van was equipped with two quarter-wavelength whip antennas and various equipment for receiving RZ SSB signals to function as a mobile station.

NTT also conducted parallel tests using narrowband (12.5 kHz) FM transceivers. These transceivers originally were manufactured for the Japanese cellular telephone system operating in 800 MHz bands, and were equipped with two-branch space-diversity with post-detection selection combining. In order to match the frequency band used for the RZ SSB tests, the RF frequency of the FM transceivers was converted from 800 MHz to 150 MHz band, without any impairment.

Various types of RZ SSB signals were tested - including a 1 kHz tone, phonetically balanced short speech, voice-band MODEM, and G3 facsimile signals - all operating within a conventional telephone bandwidth (from 300 Hz to 3.4 kHz). NTT appraised the various signals using following techniques: the tone signal at 1 kHz was appraised by SINAD values that were physically measured using a SINAD meter; the quality of short sentence speech signals was evaluated by Mean Opinion Score ("MOS") values; the transmission performances of voice-band MODEM signals for bit rates up to 9.6 kbps was appraised by Bit Error Rates ("BERs") that also were measured physically using a bit error counter.

The quality of both tone[6/] and speech[7/] signals for RZ SSB was comparable or superior to narrowband FM. The field test results obtained using RZ SSB for voice-band MODEM signals[8/] and G3 facsimile (at both 4.8 and 9.6 kbps)[9/] were excellent, and substantiated the results obtained through a series of indoor tests conducted by NTT. Additionally, the G3 facsimile tests demonstrated that the RZ SSB system is fully capable of handling facsimile transmission without additional special equipment, as compared to the need for additional hardware when using the widespread digital cellular systems for facsimile. Based on these tests, the independent MPT working group concluded in March 1992 that RZ SSB represented the best available narrowband technology for operating in the VHF bands.

In addition to these field tests, extensive indoor experimental work has been conducted, including voice-band MODEM transmission at over 9.6 kbps. In these tests, Rayleigh fading simulators were used to simulate the mobile radio environment.[10/] This experiment revealed that RZ SSB technology is transparent up to 19.2 kbps MODEM signal transmission, even in fading environments. Therefore, the maximum spectrum efficiency for RZ SSB is 19.2 kbps/5 kHz (3.84 bits/Hz).

6/ Test results are shown in Figs. 1, 2 and 3. Under the thermal noise, SINAD values exceed 40 dB, as shown in Fig. 7(a).

7/ Test results are shown in Fig. 4.

8/ Test results are shown in Fig. 5.

9/ Test results are shown in Fig. 6.

10/ Test results are shown in Figs. 7 and 8.

IV. DEMONSTRATIONS OF RZ SSB IN THE U.S..

A prototype RZ SSB system was demonstrated in early 1995 in both Washington, D.C. and Denver, Colorado. In each demonstration, a base station featuring an RZ SSB transceiver operating in the transmit mode and a three-element Yagi antenna were set up on the roof of a building approximately 145 feet tall in the representative downtown areas. The main beam of the antenna was aimed over an area that covered the test course. Various test signals were transmitted in a 5 kHz channel at a center frequency of 220.9825 MHz. The effective isotropic radiated power ("EIRP") was approximately 13 watts.

A van was equipped to operate as a mobile station with two quarter-wavelength whip antennas and an RZ SSB transceiver operating in the receive mode. The two antennas were separated on the roof of the van by about 0.2 wavelength to permit the use of the space diversity reception technique.

The signals transmitted from the base station during the demonstrations were received by the mobile station as it traveled around the test courses at speeds of up to 60 mph. Routes were chosen which allowed tests to be conducted at various speeds as well as various field strengths.

During the demonstrations, three information signals were tested: analog voice, 9.6 kbps data modulated with 16 QAM (ITU-T V.29), and G3 facsimile at a data rate of 9.6 kbps. The clarity of the analog voice received in the mobile station was excellent. Degradations due to a mistuned carrier or ignition noises were not detected.

With respect to the data transmission tests, bit error rate characteristics were dependent on the received signal levels but were not strongly dependent on the vehicular speeds. However, even when the 9.6 kbps data was received in severe fading environments due to terrain variation, bit error rates were generally less than 0.1 percent, even though error correction techniques were not employed. The ability to transmit 9.6 kbps data with a low error rate means that RZ SSB can be used to transmit digital voice and encrypted voice, limited in quality only by the capability of the voice coder.

A final test involved the G3 facsimile transmission (at 9.6 kbps) of a photographic image and a standard business letter at speeds of more than 60 mph. The results of this test were likewise excellent, even in severe fading environments.

V. FEATURES AND ADVANTAGES OF RZ SSB.

The key features of RZ SSB are summarized in Table 1.

A. Spectrum Efficiency.

1. Channel Spacing and Carrier Separation.

Single Carrier Per Channel ("SCPC") systems[11/] require frequency guard bands for each channel on the frequency axis. In the case of RZ SSB, which can support the SCPC structure, the total guard band required is only 1.6 kHz (0.8 kHz x 2), even for 5 kHz channel spacing. This is due to use of the steep bandpass filter in the RZ SSB receiver. Therefore, with a 3.1 kHz information

11/ SCPC systems support individual channels, small groups of channels, and also larger, networked systems.

bandwidth, RZ SSB can realize full adjacent channel loading with a 5 kHz channel spacing, allowing for efficient channelization.

2. Comparison to Narrowband TDMA Systems.

a. Larger Frequency Guard Bands are Required for TDMA.

Narrowband TDMA systems for land mobile radio services require the use of frequency guard bands in order to avoid interference between adjacent channels. The reason for this is briefly as follows.

A widely used digital modulation technique for narrowband TDMA systems is a $\pi/4$ phase-shift quadrature phase shift keying ("$\pi/4$-QPSK"). To obtain a compact power density modulation spectrum, an amplitude shaping pulse is introduced as a square root cosine pulse characterized by roll-off factor α.[12/] When a truncated time domain pulse is used to generate the $\pi/4$-QPSK signal for transmission, truncation of the pulse will regenerate some side lobes.[13/] These side lobes cause adjacent channel interference and must be minimized to meet the Commission's

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12/ If the radio channel is affected by flat fading and additive white Gaussian noise (thermal noise), then the square root filtering operations between the transmitter and receiver will optimize the signal to noise ratio at the output of the receiver filter at the sampling instants. The roll-off factor usually lies between 0 and 1. Using a smaller α results in a more compact power density spectrum, but the link performance becomes more sensitive to errors in the symbol timing. The U.S. digital cellular system ("USDC or IS-54 standard") uses $\alpha = 0.35$, while the Japanese personal digital cellular system ("PDC") uses $\alpha = 0.5$.

13/ JERRY D. GIBSON, THE MOBILE COMMUNICATION HANDBOOK (IEEE Press/CRC Press 1996). Data transmission for users of TDMA systems occurs in bursts. Therefore, data windowing also is required to produce a compact spectrum.

emission mask.[14] Prior to demodulating the $\pi/4$-QPSK signal in a receiver, therefore, a band-pass-filter ("BPF") having a linear phase response feature is required to limit the thermal noise power. The linear phase region of the BPF should be wide enough to support the Nyquist condition to avoid introduction of inter-symbol-interference ("ISI"), which degrades the bit error rate performance. Such a BPF is difficult to realize with narrowband characteristics allowing for adjacent channel allocation.[15]

For example, the PDC system employs a 3 (or 6) channel TDMA technique and requires carrier separation of 50 kHz, although channel spacing is only 25 kHz.[16] Therefore, a large part of the available spectrum must be allocated for the numerous guard bands required by narrowband TDMA systems. Thus, the number of usable channels is reduced. As mentioned above, RZ SSB technology requires only minimal frequency guard bands, thereby increasing the number of user channels that can be accommodated.

b. Frame Efficiency is Reduced with TDMA.

When TDMA systems are used, frame efficiency is reduced. TDMA systems communicate with each other via non-overlapping time-sequenced

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14/ The reduced band-width offered by a square root raised cosine pulse-shaping requires linear amplifiers.

15/ T. Takami, S. Saito, S. Tomisato and Y. Yamao, "Nyquist QPSK Transmission Using Rational-Function Filter for Mobile Radio," IEEE VTC '91 St. Louis (May 1991).

16/ In the USDC/IS-54 system, the channel spacing and carrier separation are 30 and 60 kHz, respectively.

transmission bursts. Therefore, TDMA systems require a guard time in order to avoid unnecessary collision of burst signals emitted from each up-link (mobile to base station) transmitter. Furthermore, in TDMA systems, each burst is composed of a frame signal, which consists of preambles, synchronization words, etc., in addition to the information digits for each slot. The preambles, synchronization words, etc., occupy a substantial portion of each frame. As a result, TDMA systems can achieve only 80% bit-utilization in the frame of a traffic channel. RZ SSB technology does not suffer from this limitation.

c. Intrinsic Receiver Noise Power is High with TDMA.

Computing receiver noise and the Signal to Noise Ratio ("SNR") at a receiver is an important part of determining coverage and quality of service in mobile communications systems. The intrinsic noise power of a receiver is calculated as $N_0 = kTBF$, where k, T, B, and F are Boltzmann's constant, room temperature, equivalent noise bandwidth, and noise figure of the receiver system, respectively.

In the Japanese PDC (25 kHz TDMA) system, the equivalent noise bandwidth is approximately 21 kHz. The wide bandwidth is required to get good error performance for the received digital stream, as TDMA must pay the "spectrum penalty" mentioned above. On the contrary, the equivalent noise bandwidth for RZ SSB is only 3.4 kHz. Therefore, the receiver noise power level of RZ SSB is 7.9 (= 10 log (21.0/3.4)) dB less than that of TDMA, assuming that the noise figure of the RZ SSB receiver is the same as that of the TDMA receiver.

d. Channel Degradation

When TDMA receivers using a common RF channel happen to locate in an area of unusable signal strength, they could all fail to achieve frame synchronization, preventing operation. In the same area, an SCPC receiver using the same RF channel might be unable to communicate, but others on adjacent channels would be able to communicate because they do not depend on frame synchronization for operation. Thus, the SCPC scheme improves the robustness and redundancy of communications in systems having several voice channels.

3. No Error Correction Techniques.

RZ SSB was designed to support digital as well as analog signals coming from the conventional telephone line. Space diversity reception is effective for both kinds of signals in coping with severe fading, as verified by the field testing and demonstrations described above. Therefore, excellent results can be achieved, even without use of error correction techniques. This allows for 100% through-put of digital information.

4. TDD and TDMA Operation.

When a 5.6 kbps VOCODER, e.g., PSI-CELP (which is currently installed in the PDC system in Japan) is used with RZ SSB, Time Division Duplexing ("TDD") becomes possible using a single RF frequency, because RZ SSB can transmit and receive a 14.4 kbps digital signal through fading environments. However, the service area may be relatively limited.

If two neighboring 5 kHz channels are used to create a 10 kHz channel, a 3 channel-TDMA system can be realized, by introducing 12.0 kbps bit rate transmission using RZ SSB and 5.6 kbps PSI-CELP. In this case, both the upper side-band and lower side-band are utilized for digital signal transmission.

B. Wide Variety of Transmittable Signals.

As stated above, RZ SSB technology was originally designed to carry digital as well as analog signals from the conventional telephone line even through severe fading, and its ability to do so has been verified. Therefore, RZ SSB can be used to transmit and receive a wide variety of signals in a 5 kHz channel spacing. It is compatible with FDMA (SCPC), TDMA, and TDD multiple access techniques.

RZ SSB supports analog voice, exhibiting natural sound characteristics. Analog voice can preserve the subtle intonations of normal speech, aiding communication by allowing for speaker recognition. Analog voice with RZ SSB has been demonstrated to be easily and correctly perceived by the listener, even in severe fading environments and even in the presence of severe noise.

RZ SSB can also be used for digital voice signals, and is compatible with a variety of voice coders, including VSELP, and PSI-CELP. As a consequence, encrypted voice communication can be supported easily. However, RZ SSB can neither prevent the abrupt cut-off of digital voice that can occur when a user approaches the border of a service area, nor improve the artificial sound that digital voice can exhibit. These features of digital voice are a consequence of digital transmission itself in mobile radio environments, and of the level of digitization employed, and not of the modulation technology used.

RZ SSB supports data transmission, at speeds of up to 19.2 kbps, using voice-band MODEM. As noted above, Bit Error Rates ("BERs") are extremely low, even without error correction, and even in fading and noisy environments. Exploiting its data transmission capabilities, RZ SSB can be used to transmit and receive photographic images as well as text signals of G3 facsimile (at 9.6 kbps), as described above.

Moreover, even in a fading environment, RZ SSB can support a series of still JPEG pictures (Motion JPEG - Joint Photographic Experts Group), a standard that was originally developed for the publishing business. The JPEG image is compressed as compared to the original image, and this compression permits JPEG images to be transmitted and received using conventional voice-band MODEM equipment. Tests conducted using a laboratory test bed simulating severe land mobile radio environments have demonstrated the excellent quality of decoded JPEG images transmitted using RZ SSB.

C. Seamless Interface with Telephone System.

RZ SSB can accommodate, in a 5 kHz channel, an information signal having a bandwidth identical to the conventional telephone bandwidth (300 Hz ~ 3.4 kHz), allowing RZ SSB equipment to seamlessly interface with signals coming from the conventional telephone lines without any additional equipment.

D. Interoperability.

Combining RZ SSB with other technologies in a multimode radio should add only nominally to the size and cost of such radios, and would provide users with the flexibility to easily migrate to narrower channelization plans and/or to communicate interoperably with others using equipment based on other technologies. For example, most current public safety communication systems use analog FM technology. RZ SSB technology may easily be combined with this technology because the configuration of an RZ SSB receiver is similar to that of an FM receiver except for the LSI linearizer, described above.

E. Handheld Equipment.

The components of an RZ SSB transceiver can be incorporated into handheld radios using current micro-electronics techniques. NTT is currently studying the various ways in which diversity reception may be implemented in hand-held units. The important function of diversity reception is to decrease the range of signal level and phase variation in a mobile environment. For this reason, it is not required at slow speeds, such as walking speed. For applications in which a handheld may be used at high speeds, a second antenna (even if less than optimal size) installed in a hand-held unit should be able to mitigate the effects of decreases in signal levels, even though the second antenna gain may be decreased.

In cases in which automobiles will be primary points of communications, two antennas could be installed on the automobile, and connected to a dash-board unit into which the hand-held unit fits. When traveling in the car, the hand-held unit would be connected to the two antennas, and diversity reception would be achieved.

In the case of narrowband technology, the coherency of RF power emission is relatively high. When designing hand-held units, assessing the maximum RF power level for a human body is very important. NTT expects, however, that handheld units incorporating RZ SSB can be manufactured that meet all Commission-prescribed guidelines.